

1                    DISCRETIONARY DOTTING FOR ARTIFACT CONTROL  
2                    IN INCREMENTAL PRINTING

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4  
5           RELATED PATENT DOCUMENTS

6  
7           Closely related documents are other, coowned U. S.  
8           utility-patent applications filed in the United States  
9           Patent and Trademark Office generally contemporaneously  
10          with this document — and also hereby incorporated by  
11          reference in their entirety into this document. One is in  
12          the names of Lain et al., and identified as Hewlett Pac-  
13          kard Company docket number PD-60002639Z31, and entitled  
14          "RANDOMIZED SUPERPIXELS TO ENHANCE MULTILEVEL IMAGE QUALI-  
15          TY IN ECONOMICAL, FAST INCREMENTAL-PRINTING ERROR DIFFU-  
16          SION" — and subsequently assigned utility-patent applica-  
17          tion serial 09/\_\_\_\_,\_\_\_\_, and issued as U. S. Patent  
18          6,\_\_\_\_,\_\_\_\_. Lain is of interest for general context but  
19          especially the implementation of random selection of spe-  
20          cific dots to be discretionarily augmented. Another such  
21          document is in the names of Garcia-Reyero et al., and  
22          identified as Hewlett Packard Company docket number PD-  
23          60990037Z23, and entitled "IMPROVEMENTS IN AUTOMATED AND  
24          SEMIAUTOMATED PRINTMASK GENERATION FOR INCREMENTAL PRINT-  
25          ING" — and subsequently assigned utility-patent applica-  
26          tion serial 09/\_\_\_\_,\_\_\_\_, and issued as U. S. Patent  
27          6,\_\_\_\_,\_\_\_\_. The Garcia-Reyero document and others cited  
28          in it are particularly pertinent as to masking strategies  
29          implemented through a family of program techniques dubbed  
30          "Shakes", especially including downweighting of print  
31          elements (e. g. nozzles) that are weak or misaimed; these  
32          strategies assume that such elements have been or will be  
33          identified. A third related document is in the names of  
34          Cluet et al., and identified as Hewlett Packard Company

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1 docket PD-60990047Z28, and entitled "PRINTING AND MEASUR-  
2 ING DIRECTLY DISPLAYED IMAGE QUALITY, WITH AUTOMATIC  
3 COMPENSATION, IN INCREMENTAL PRINTING" — and subsequently  
4 assigned utility-patent application serial 09/\_\_\_\_,\_\_\_\_,  
5 and issued as U. S. Patent 6,\_\_\_\_,\_\_\_\_. Cluet teaches how  
6 to find bad nozzle groups, to facilitate compensating in  
7 weights as by the Garcia-Reyero strategies. Also of in-  
8 terest is U. S. application serial 09/252,163, later is-  
9 sued as U. S. Patent 6,\_\_\_\_,\_\_\_\_, of Borrell — a coworker  
10 of the present inventor — who adds or "propletes" inking  
11 to linearize saturation. More remote but of interest are  
12 depletion techniques generally, and particularly work on  
13 reverse undercolor adjustments e. g. in U. S. 5,473,446 of  
14 Perumal.

#### 15 16 17 18 FIELD OF THE INVENTION

19  
20 This invention relates generally to devices and  
21 procedures for printing text or graphics on printing media  
22 such as paper, transparency stock, or other glossy media;  
23 and more particularly to a scanning thermal-inkjet machine  
24 and method that construct text or images from individual  
25 ink spots created on a printing medium, in a two-dimen-  
26 sional pixel array. The invention is applicable to vari-  
27 ous kinds of printing devices including facsimile machines  
28 and copiers as well as printers. The invention employs  
29 printmode techniques to conceal printing artifacts, par-  
30 ticularly including certain forms of banding.

1     BACKGROUND OF THE INVENTION

2  
3         (a) The banding problem — White or light striations  
4 along the scan axis, often called "banding", have been a  
5 commonly noted problem since the earliest days of incre-  
6 mental printing by inkjet and like printing devices, and  
7 ironically have yet to be fully resolved. A primary rea-  
8 son for the seeming stubbornness of these artifacts is  
9 that several different kinds and causes of banding occur,  
10 so that no single insight or cure can be possible.

11         Many banding types are now under much better control  
12 than originally. At the same time, however, new solutions  
13 for various banding problems continue to be needed because  
14 of rising quality standards and increasingly difficult op-  
15 erating conditions — due e. g. to marketplace demands for  
16 high throughput.

17         The present invention is directed mainly to banding  
18 that is caused by dot-placement error (DPE) — in other  
19 words, errors produced by printing elements (inkjet noz-  
20 zles etc.) that are not aimed correctly. It also helps  
21 conceal banding due to elements that are not working at  
22 all or are weak, as for example inkjet nozzles that are  
23 plugged or whose firing heaters are not of the correct  
24 resistance.

25         In all such cases, rows of the image pixel grid that  
26 should be printed at some nominal saturation level are in-  
27 stead printed either lightly or not at all, and this is  
28 perceived as a white or light line across the image. Such  
29 lines may appear singly or in clusters — since the print-  
30 element failures that produce them often occur in groups.

31  
32         (b) The search for a robust solution — In this field  
33 the term "robust" means resistant to varied severity of  
34 the problem and to a variety of operating conditions, in-

1 cluding some conditions that may be unexpected. The act  
2 of aiming one single dot into a regular grid is actually  
3 the least robust method, as far as banding is concerned.

4 Such operation does display a good degree of peak  
5 image quality. The chance of achieving this optimum per-  
6 formance, however, is small due to the loose tolerances of  
7 economical printing systems (i. e. printing elements and  
8 positioning mechanisms).

9 A classical approach to mitigation of banding is mul-  
10 tipass printing — and this technique is generally accep-  
11 ted since multipass printing also helps resolve several  
12 other important problems, though it does degrade through-  
13 put. Such printing divides each swath of an image into  
14 contributions made during several scans of the print-ele-  
15 ment array (e. g. pen) across the image.

16 This type of printing also advances the print medium,  
17 between scans or groups of scans, by some fraction of the  
18 array length. Each advance brings a different printing  
19 element (e. g. nozzle) of the array into alignment with a  
20 particular pixel row on the medium.

21 The idea is that any artifact due to a particular  
22 print element in an array — at some given row on a print-  
23 ing medium — tends to be buried and thus concealed in the  
24 contributions made by other elements of the same array.  
25 Classically, however, unfortunately each other element has  
26 its own job to do, so that actually light or white streaks  
27 due to impairment of one printing element remain discer-  
28 nible even though superposed upon patterns of colorant  
29 dots contributed by other elements.

30 In the past it has been supposed that multipass  
31 printing itself would suffice to adequately conceal band-  
32 ing of the light-line or white-line type. The error in  
33 such suppositions is due in part to escalating marketplace

1 standards of quality — but also arises in large part from  
2 the evolving character of print-element malfunction.

3 Early incremental-printing systems, and particularly  
4 the printing-element arrays (nozzle plates etc.) were es-  
5 sentially machine tooled, and short, and rather precisely  
6 constructed — particularly as to aiming. Unfortunately  
7 these were both slow in printing (because of their short-  
8 ness) and expensive. Progressively longer inkjet printing  
9 arrays have been made economically possible by the advent  
10 of tape-automated bonding ("TAB") techniques with laser  
11 perforation, but only at the cost of considerable impreci-  
12 sion in dot placement (sometimes characterized as  
13 "directionality").

14 Performance of TAB-fabricated printheads has now im-  
15 proved markedly. Nevertheless the capability of printing-  
16 element arrays to misdirect colorant continues to outstrip  
17 the capability of multipass printing to hide such phenom-  
18 ena. This is an example of the importance of robustness  
19 in solutions to the banding problem.

20 On the other hand, users may no longer be willing to  
21 wait quite as contentedly while a printer produces excel-  
22 lent image quality through painstaking six- or ten-pass  
23 printmodes. This is an example of the influence of esca-  
24 lating marketplace standards.

25  
26 (c) Printmode techniques — Modern multipass printing  
27 has evolved greatly, with highly sophisticated strategies  
28 ("printmasking") to allocate colorant deposition as among  
29 passes. These strategies include pseudorandom allocation,  
30 intended mainly to reduce patterning artifacts that come  
31 from repetitive interaction of cyclical mechanism errors  
32 with dither masks (rendition threshold matrices) — or  
33 even with repeating phenomena inherent in the more-elemen-  
34 tary allocation strategies themselves.

1 Sometimes these patterning artifacts, too, are called  
2 "banding" but for purposes of the present document that  
3 nomenclature is only confusing. What is of interest here  
4 is light- or white-line banding.

5 These strategies do incidentally help to swamp out  
6 the effects of any individual element malfunction in a  
7 complex of patterns, both intended and otherwise, gener-  
8 ated by other elements. These methodologies are merito-  
9 rious and serve their purpose well; overall, however, the  
10 correction of white- and light-line banding is not the  
11 main function of printmasking; and such banding persists.

12 Another very modern printmasking development is the  
13 use of print-element usage weighting, and complementary  
14 replacement regimens, in attempts to eliminate image-qual-  
15 ity degradation due to known malfunctioning elements. The  
16 previously mentioned document of Garcia-Reyero, and other  
17 references cited in that document, introduce a great body  
18 of such technique.

19 All such efforts, however, require some sort of test-  
20 ing to identify malfunctioning elements; one such approach  
21 is presented in the above-mentioned document of Cluet.  
22 Techniques that require testing are somewhat disfavored in  
23 that they implicate operational delays and additional ex-  
24 pensive apparatus — as well as costs for colorant (and  
25 sometimes printing medium) consumed in the tests.

26 Hence it remains desirable to find ways to eliminate  
27 or at least greatly reduce the appearance of light- or  
28 white-line banding without testing the printing elements.  
29 A robust solution must be one that deals effectively with  
30 dot-placement error that occurs in a variety of forms and  
31 intensities.

32  
33 (d) Etiology of banding — The foregoing discussions  
34 point to an important need for deeper understanding of the

1 detailed causes of white/light-line banding — and in par-  
2 ticular its sensitivity to both the character and severity  
3 of dot-placement error. The present inventor has consid-  
4 ered and experimented in this area very extensively, and  
5 along the way to the present invention has developed im-  
6 portant insights into these facets of the banding problem.

7 These insights thus are no part of the related art  
8 but rather are regarded as part of the creative processes  
9 underlying the present invention. Accordingly they will  
10 be reserved for the following sections of this document  
11 that relate to the invention.

12  
13 (e) Use of two or more drops — For the present sec-  
14 tion it may be noted how the prior art has applied more  
15 than one quantum of colorant (e. g. inkdrop) to a printing  
16 medium. These observations will be presented in a concep-  
17 tual framework that will be useful for later discussions.

18 One relatively primitive technique is to use two  
19 quanta wherever any colorant is to be applied. In other  
20 words — on a scale from zero 121 (Fig. 2) to full satura-  
21 tion 122 (for instance solid black) — when the first step  
22 is taken away from zero inking 121 in highlight regions,  
23 it is taken by printing not one but two inkdrops in some  
24 pixel.

25 At the other end 122 of the scale when the last step  
26 is taken to achieve fullest available saturation, it is  
27 taken by adding not just one more last drop in some pixel  
28 but rather two. The continuum between these extreme  
29 points is followed in exactly the same way, defining a  
30 linear gradation 123 (Fig. 2) with two inkdrops (or other  
31 fixed count of quanta, depending on the writing system)  
32 added at each increment. When those last two drops have  
33 been added, then either zero or two dots have been placed  
34 into each pixel in the grid — or, for a system that does

1 not use every pixel, into each pixel that is to be ad-  
2 dressed at all.

3  
4 (This full-usage pixel-count condition represents  
5 "full coverage" or "100% coverage" for the particular  
6 writing system. For purposes of this document, the work-  
7 ing definition of "full coverage" or "100% coverage" is  
8 thus not a matter of calculating inked area. Rather it is  
9 a matter of counting colorant quanta, e. g. dots, per pix-  
10 el — for comparison with the total number of quanta per  
11 pixel employed or permitted.)

12  
13 The objectives of such double-dot-always operation  
14 may include obtaining, at each point along the scale,  
15 better colorimetric saturation than available with single-  
16 drop increments — and may also include providing finer  
17 drops and thereby better liquid control. This technique  
18 is sometimes called "dumb double dotting".

19 As to banding, for reasons that will later become  
20 clear, dumb double dotting is slightly more robust than  
21 single-drop printing. Accompanying granularity, however,  
22 is very high. Moreover this type of printing is not com-  
23 patible with some printing media — and fails to complete-  
24 ly resolve the banding problem.

25  
26  
27 Conventional orderly multilevel printing proceeds by  
28 a different sequence. In addition to the highlight end  
29 121 (Fig. 3) and shadow end 122 of the scale, here there  
30 is an additional, intermediate breakpoint 124 which repre-  
31 sents the greatest saturation attainable with single  
32 dotting. Because the later and higher-dot-count condition  
33 122 exists, however, breakpoint 124 is not "full coverage"  
34 or "100% coverage".



1           In developing progressive fractions of area fill,  
2       this system first assigns one individual drop for place-  
3       ment in each one of a progressively rising number of pix-  
4       els — following a linear relation 125 (Fig. 3) to the  
5       breakpoint 124. This linear curve represents the number  
6       of pixels holding one dot.

7           At the breakpoint 124 one dot is placed in each pixel  
8       — or, again, in each pixel that is to be addressed at  
9       all. As suggested above, although this pixel count may  
10      yield maximum single-dot saturation or perhaps even "full  
11      single-dot coverage", for purposes of this document it  
12      will not be identified as "full coverage" or "100% cover-  
13      age".

14          Thereafter for continuing higher fractions of area  
15      fill it is necessary to begin to add another dot to some  
16      pixels. The number 126 of pixels holding one dot thus de-  
17      clines while the difference is taken up by a complementary  
18      linear curve 127, representing the number of pixels hold-  
19      ing two dots.

20          The latter line ascends to the above-identified full-  
21      saturation, "full coverage" or "100% coverage" point 122.  
22      In this region between the breakpoint 124 and the shadow  
23      or full-saturation end 122 of the scale, the total number  
24      of inked pixels is a sum of single-dot pixels 126 and  
25      double-dot pixels 127.

26          The possibility remains, however, that some pixels  
27      are entirely unused. As will shortly be seen, for in-  
28      stance, some systems use only every other pixel; such  
29      pixel structure has been used particularly in conjunction  
30      with oversize dots, relative to the grid pitch.

31  
32  
33          Still within the prior art, conventional orderly mul-  
34      tilevel printing is capable of managing still larger num-

1    bers of dots per pixel. This is accomplished by extension  
2    of the same regimen just described.

3        More specifically, the system first adds not one  
4    breakpoint 124 — having the same significance described  
5    above — but also a second intermediate breakpoint 131  
6    (Fig. 4) related to the greatest saturation available with  
7    double dotting; the system then connects the several crit-  
8    ical states linearly as before. Thus the first ascending  
9    segment 125 is still the growing number of pixels holding  
10   one dot; and the second, falling segment is the decline of  
11   such pixels as the number 127 of pixels holding two dots  
12   rises.

13        When that latter curve 127, however, now reaches full  
14   coverage by two dots per pixel — or per pixel that is to  
15   receive any dots at all — the saturation has now only  
16   reached the second breakpoint 131. Here, analogously, the  
17   number of two-dot pixels declines 132 (Fig. 4) while a new  
18   regime 133 — namely the number of three-dot pixels —  
19   completes the rise to full three-dot coverage 122.

20        In this region the total number of pixels is the sum  
21   of double-dot pixels 132 and triple-dot pixels 133. At  
22   the 100%-coverage point 122, three dots reside in every  
23   pixel — or, here again, at least every pixel that is ever  
24   to receive any dots.

25        The multilevel "orderly" methods have potential for  
26   improvement relative to binary printing, because a single  
27   drop can be smaller than before. Therefore these metho-  
28   dologies can improve granularity relative to binary print-  
29   ing — but no improvement is obtained in the initial band-  
30   ing behavior, in the region from zero area fill 121 to the  
31   point 124 where each pixel is occupied by one drop. Un-  
32   fortunately it is in the upper ends of these ranges, i. e.  
33   the middle tones, where banding is most conspicuous to the  
34   eye.

1           There is another noteworthy variant of a "checker-  
2 board" system — i. e., a rectangular pixel grid in which  
3 the only pixels used are those in a checkerboard pattern.  
4 Those of ordinary skill in this field will appreciate that  
5 such a system in principle can be made to use, say, the  
6 alternate checkerboard positions for the third dot set 133  
7 or the second dot set 127, or both.

8           In such a case, dots in the third or second set are  
9 centered between, not on, dots in the first set 125. It  
10 will also be clear that for patent purposes this is merely  
11 an equivalent of a basic checkerboard system in which all  
12 three sets share the same pixels.

13  
14           (f) Conclusion — Obstinate problems of white-line  
15 and light-line banding thus continue to impede achievement  
16 of uniformly excellent inkjet printing — at high through-  
17 put — on all industrially important printing media. Thus  
18 important aspects of the technology used in the field of  
19 the invention remain amenable to useful refinement.

20  
21  
22  
23  
24       SUMMARY OF THE DISCLOSURE

25  
26           The present invention introduces such refinement.  
27 Before providing any relatively rigorous discussion or  
28 definition of the invention, this document will first of-  
29 fer an informal introduction to the previously mentioned  
30 insights that underlie the invention.

31           It will be understood, however, that the merit of the  
32 invention stands on its own. That is, the effectiveness  
33 and validity of the invention do not depend upon the accu-  
34 racy or incisiveness of the philosophy presented here.

1       The insights discussed here concern the relationship  
2 between the character or severity of (1) DPE and (2) re-  
3 sulting light/white-line banding. These discussions and  
4 analyses proceed from simple geometrical observations,  
5 which are made possible by focusing upon the printing of a  
6 monochrome area fill — as a simplified model of the  
7 environment of the problem.

8       Some analyses go further, considering most particu-  
9 larly the printing of a nominally solid area fill. Again,  
10 from the later detailed description it will be seen very  
11 clearly that the invention is not limited to solid fills,  
12 but very much to the contrary applies particularly to mid-  
13 tone and even highlight levels.

14       The problem and its solution by the present invention  
15 are thus far more general than these models may suggest.  
16 Nevertheless they are useful models for discussion, and it  
17 is important only to later return to the recognition that  
18 there are other colors in the system as well, and that  
19 they too are subject to the techniques of the invention.

20  
21       In an ideal prior-art pixel grid, a uniform mono-  
22 chrome solid area fill has a large multiplicity of circu-  
23 lar dots 111, 112 (Fig. 1, top view). In this particular  
24 diagram, each dot is assumed to be of diameter  $\underline{D}$  twice the  
25 grid pitch  $\underline{d}$  and also with perfect spacing  $\underline{s}$  on centers at  
26 twice the grid pitch along each row or column. In alter-  
27 nate rows and columns, however, the dot centers are dis-  
28 placed so that each dot is centered, checkerboard fashion,  
29 on a white area left uninked by its diagonal neighbors.

30       As the drawing shows, the entire image area is filled  
31 with at least one layer of ink — and from simple geomet-  
32 rical calculation, subareas 113 roughly aggregating 0.57  
33 of the total area are covered by two layers. Since more  
34 than half the grid is double-inked it might be supposed

1 that such a geometry is very robust in resistance to dot  
2 placement error.

3 Surprisingly, however, this is not so — as seen by  
4 the entirely uninked space 114 that appears if just one  
5 dot 112 (Fig. 1, lower view) is misplaced rightward and  
6 downward by only about three-fifths of the grid pitch.  
7 (This represents a relatively severe degree of DPE.) In  
8 this lower view the newly assumed position of dot 112 is  
9 flagged by a vertical and horizontal crosshair pattern,  
10 now clearly off-center.

11 The result of such placement error is to destabilize  
12 the average lightness (measured for instance as  $L^*$ ) or in  
13 other words to display white- or light-line banding. One  
14 helpful way to think about the situation is this:

15  
16 (1) coverage is initially full on a dot-count basis be-  
17 cause all pixels that are to be addressed have been  
18 addressed (even though this is only half the total  
19 number of pixels);

20  
21 (2) nominally, coverage is initially complete on an  
22 areal-inking basis too, as there is nominally no  
23 white space showing: the circular dots all neatly  
24 and perfectly touch horizontal and vertical neighbors  
25 in four-point coincidences — i. e. point contacts —  
26 and

27  
28 (3) therefore, if any of the dots is displaced slightly,  
29 coverage can only go down.

30  
31 The situation can worsen rapidly if any of the other dots  
32 above and to the left also happens to be misplaced away  
33 (not shown) from the one that is moving down and to the  
34 right.

1        Suppose, however, that at the correct position of the  
2        dot 112 which happens to be incorrectly placed, there is a  
3        directly superimposed second dot 115 (Fig. 5 upper view,  
4        shown in the dashed line). If the placement of the first  
5        dot 112 remains accurate, the second dot 115 may in effect  
6        be hidden on top of (or below) the first dot 112, and may  
7        not even be noticed.

8        When the unknown effects of dot placement error put  
9        the first dot 112 elsewhere, as shown in the lower view of  
10       Fig. 5 (still flagged as in Fig. 1 by the diametral cross-  
11       hairs), then the extra dot 115 may seem to come out of  
12       nowhere to cover the space 114 that would otherwise be  
13       blank. As the drawing accurately suggests, the overall  
14       result may appear more grainy — but the average lightness  
15       is more constant.

16       A more pragmatic way of expressing the same thing is  
17       that the light and white lines identified as "banding" may  
18       be suppressed, either partially or entirely. These conse-  
19       quences have been validated through physical testing.

20       It will be understood that the beneficial results in-  
21       dicated in the simple diagrams are subject to statistical  
22       fluctuation. If the space 114 uncovered by DPE does not  
23       happen to be coincide with the extra dot 115, then the re-  
24       sult for that particular space 114 may be extra granulari-  
25       ty with no  $L^*$  stabilization.

26       In general, however, this topic is merely a matter of  
27       sensitivity and optimization: a representative uncovered  
28       space 114 is generally far smaller than a typical dot 112  
29       or 115. Hence the likelihood of a backup dot 115 catching  
30       and correcting uncovered space 114 is quite high, even for  
31       a dot-count fraction of just one dot in a field of seven  
32       as illustrated.

33       This is also true even on an areal basis, that is for  
34       relatively small fractions of backup-dot area 115 compared

1 with the overall area inked (i. e. the aggregate area of  
2 all the dots illustrated). The detailed discussion which  
3 follows this summary section will teach some principles  
4 for selecting both the dot-count fraction and the place-  
5 ment of the backup dots.

6 In this document these backup dots 115 will sometimes  
7 be called "discretionary dots"; and the technique, "dis-  
8 cretionary dotting" (DD). The dot-count fraction (e. g.,  
9 one in a field of seven) mentioned just above is thus the  
10 "DD fraction" or "DD ratio".

11 To simplify discussion, and without any implication  
12 as to difference in character of individual markings, all  
13 the other dots — i. e. the original or prior-art dots  
14 111, 112 — will be called the "conventional" dots. In  
15 general, discretionary dots 115 and conventional dots 112  
16 are identical — although it is within the scope of the  
17 invention to make them different if desired.

18 It may be noted that DD, being statistical, never  
19 requires any knowledge of the specific location for a dot  
20 112 that is actually misplaced — or of the specific  
21 printing element (nozzle) whose incorrect functioning  
22 causes that misplacement.

23  
24 Now with these insights in mind, discussion here will  
25 turn to a somewhat more rigorous discussion of the inven-  
26 tion. In its preferred embodiments, the present invention  
27 has several aspects or facets that can be used independ-  
28 ently, although they are preferably employed together to  
29 optimize their benefits.

30 In preferred embodiments of a first of its facets or  
31 aspects, the invention is apparatus for incremental print-  
32 ing of an image. The apparatus include some means for  
33 addressing a region of the image at less than full (100%)  
34 coverage (on a pixel-count basis as defined above). For

1 purposes of generality and breadth in discussing the  
2 invention, these means will be called simply the "partial-  
3 coverage means".

4 The apparatus also includes some means for adding  
5 further colorant quanta to selected pixels already receiv-  
6 ing that colorant as part of the less-than-full coverage  
7 within the region. These latter means, again for breadth  
8 and generality, will be called the "adding means".

9 The phrase "that colorant" here (or "said colorant"  
10 in certain of the appended claims) calls attention to the  
11 point that the colorant is of the same basic color — al-  
12 though possibly a different dilution. In other words,  
13 this first main facet of the invention relates to adding  
14 more of a particular color of ink.

15 Throughout this document including most of the ap-  
16 pended claims, except where otherwise specified or clear  
17 from the context, it is to be understood that what is  
18 being discussed is a treatment that is applicable — and  
19 preferably is actually applied — to each color or dilu-  
20 tion. Repeatedly reminding the reader of this understand-  
21 ing would be needlessly cumbersome, and distracting as  
22 well.

23 Based on cooperation of the partial-coverage means  
24 and the adding means, the amount of colorant printed in  
25 some pixels within the region is zero, in others is a  
26 first nonzero number of colorant quanta, and in still  
27 others is a second nonzero number of colorant quanta. The  
28 first and second nonzero numbers are different.

29  
30 Otherwise the maximum values of the two nonzero num-  
31 bers are each limited only by the "full coverage" quantum-  
32 per-pixel counts. Thus each of the nonzero numbers may be  
33 one, or less than or greater than one — depending primar-



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1 ily upon the size of the dot formed in the image by a  
2 colorant quantum.

3 For example if the dot is generally circular and its  
4 diameter is twice the height or width of a single pixel in  
5 the grid, then nominally complete areal inking (nominal  
6 elimination of white space, assuming no DPE) is usually  
7 attained by placing one quantum at every other pixel,  
8 checkerboard-fashion. System design will typically there-  
9 fore establish this condition, one-half quantum per pixel  
10 on-average, as "full coverage". (This can instead be  
11 expressed, however, as one quantum per addressed pixel,  
12 i. e. one quantum per pixel that is ever used.)

13 On the other hand if the dot diameter is equal to the  
14 diagonal of the pixel grid, then nominally complete areal  
15 inking is usually attained by placing one quantum at each  
16 pixel, on-average. In this case it is this condition that  
17 will typically be established as "full coverage".

18 For dots intermediate in size between these two ex-  
19 amples, other numbers of quanta intermediate between one-  
20 half and one will ordinarily provide nominally complete  
21 removal of white space — and so ordinarily will be iden-  
22 tified as "full coverage" or "100% coverage". (In most  
23 but not all cases, it will be possible to express the  
24 value as one quantum per addressed pixel.)

25 As seen from the foregoing, a close and complex re-  
26 lationship obtains between nominally complete areal inking  
27 and "full (100%) coverage". The two differ in subtle ways  
28 and again, for purposes of this document, to avoid ambigu-  
29 ity only the quanta-per-pixel count will be used as the  
30 measure of "full coverage" or "100% area fill", etc.

31 Those of ordinary skill in this field will understand  
32 that various other factors affect the number of quanta  
33 which provide nominal white-space elimination — and so  
34 come to be identified with "full coverage". For example

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1 where system design establishes nonsymmetrical pixels,  
2 then a very great variety of relationships with colorant  
3 quanta can arise; it would not be helpful to understanding  
4 of the present invention to try to predict here the direc-  
5 tions which such relationships might take.

6 As another example, even within the practice of the  
7 present invention it is possible to employ "dumb dotting"  
8 to provide either the underlying ("conventional") basic  
9 partial coverage or the added discretionary dots, or both.  
10 In other words, two or more inkdrops or dots may be em-  
11 ployed together as a colorant-quantum unit, for either  
12 binary or multilevel printing.

13 In such cases either the size of the quantum may be  
14 taken as plural colorant dots, or the quantum may be taken  
15 as a single dot and the number of quanta per unit consid-  
16 ered to vary. In either event the number of quanta used  
17 as the "unit" for the underlying partial coverage need not  
18 be the same as the number used as the "unit" for the added  
19 discretionary dotting.

20  
21 The apparatus further includes some means for print-  
22 ing the image including the region with the added further  
23 quanta. These means, for like reasons, will be denomina-  
24 ted the "printing means".

25  
26 The foregoing may represent a description or defini-  
27 tion of the first aspect or facet of the invention in its  
28 broadest or most general form. Even as couched in these  
29 broad terms, however, it can be seen that this facet of  
30 the invention importantly advances the art.

31 In particular this aspect of the invention first  
32 breaks the earlier tacitly observed rule that two or more  
33 quanta are provided only after a first full set has one  
34 quantum — not coexisting with some pixels that still have

1 zero. By departing from that conventional wisdom, the  
2 present invention offers a new mechanism for controlling  
3 image-quality robustness in general — and system design-  
4 ers can exploit this general mechanism for any advanta-  
5 geous purpose. In particular for present purposes it  
6 thereby enables a breakthrough in the control of banding.

7  
8 Although the first major aspect of the invention thus  
9 significantly advances the art, nevertheless to optimize  
10 enjoyment of its benefits preferably the invention is  
11 practiced in conjunction with certain additional features  
12 or characteristics. In particular, preferably the adding  
13 means also include some means for establishing a ratio of  
14 number of added-colorant pixels to total number of ad-  
15 dressed pixels; and also some means for setting the ratio  
16 to a value below one-half.

17 The examples discussed above showed that reduction of  
18 banding was accompanied by increase of grain or clumping  
19 in the image. This is a fundamental characteristic of the  
20 invention and should be confronted as a matter of tradeoff  
21 between the degree of banding that is acceptable and the  
22 degree of granularity that is acceptable.

23 In practice it is often possible to virtually elimi-  
24 nate banding with only minor amounts of graininess paid as  
25 a price. The results in this regard, however, vary mark-  
26 edly with the elements of individual images.

27 If this preference is observed, then the setting  
28 means include some means for setting the ratio to a value  
29 between 0.15 and 0.4 inclusive. In this case, the setting  
30 may be performed either automatically or by an operator,  
31 or partly by both.

32 Automatic setting of the ratio (or the automatic por-  
33 tion of setting the ratio if this task is shared with the  
34 operator) usually involves microprocessor operations in

1     which — at system startup, or earlier in the case of an  
2     ASIC — a memory position is set aside for holding the ra-  
3     tio and is so designated. These preliminary steps are  
4     helpfully regarded as "establishing" the DD ratio.

5             Most commonly, but not at all necessarily, the memory  
6     position also is filled with a default value. This entry  
7     of a default DD-ratio value is automatically setting the  
8     ratio, but semantically is not necessarily the end of the  
9     matter.

10            For example the apparatus may then automatically can-  
11    vass various environmental conditions, or characteristics  
12    of the image to be printed, or both environmental and im-  
13    age factors. Based on such collected information the ap-  
14    paratus may then proceed to develop a DD ratio and load it  
15    into the designated memory position — perhaps erasing a  
16    default value if one was previously entered — and this  
17    too is setting the ratio.

18            This step of setting the ratio may further encompass  
19    a manual selection of another value, and a loading of that  
20    value into the designated memory slot (whether or not a  
21    default value was entered earlier). This loading also is  
22    setting the ratio, and a merely alternative way of ex-  
23    pressing this semantic conclusion is to call this last-  
24    mentioned loading "yet another form or component of set-  
25    ting the ratio". Presence of such a manual step, however,  
26    is entirely consistent with the fact that, as set forth  
27    above, the several other loadings of the DD-ratio memory  
28    position are setting the ratio.

29            The ideal setting, however, may be in part a matter  
30    of esthetic preference — and also may depend in a subtle  
31    way upon particular esthetic features of individual ima-  
32    ges. Therefore a still further preference is that the  
33    setting means include some means for accepting a human op-

erator manual selection to trade off banding robustness against granularity.

If the manual-selection preference is instituted, then it is still further preferred that these accepting means include some means for expressly presenting to the operator some indicia of the tradeoff. For example, preferably the indicating means include a human-readable scale that indicates increasing banding robustness in one direction, and decreasing granularity in an opposite direction — or the equivalent.

By "equivalent" is meant some other wording that conveys the same concept. The indicia should communicate to the user in esthetic or intuitive terms what the nature of the tradeoff is.

Thus equivalents do encompass a scale marked, merely by way of example, as shown below.

better as to:  
clumping <|=|=|=|=|=|> striation  
0 1 2 3 4 5

Alternatively, "increasing banding robustness" might be expressed as "less banding" or "destreak"; while "decreasing granularity" could be called "less clumping" or "more blue noise", or "raise dot frequencies".

More-general terms, however, might not serve — since banding and granularity both impair "image quality" and even "smoothness". Also, indicating variation in only one of these two characteristics could be unsatisfactory since few users would willingly select "more banding" if the displayed alternative is "less banding".

Indications such as a scale labeled "noise" with "white" at one end and "blue" at the other at least may be neutral as to suggestion of overall image acceptability,

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1 and may thereby beneficially send the user to the instruc-  
2 tion manual or help file. The same may be true of a scale  
3 marked "spatial frequency" with "low" at bottom and "high"  
4 at top.

5 Nevertheless such indicia are needlessly cryptic as  
6 to the presence and character of the tradeoff. It may be  
7 noted that setting the control to the extreme left end of  
8 the scale as shown above may be equivalent to simply turn-  
9 ing off the feature of the present invention.

10  
11  
12 In preferred embodiments of its second major indepen-  
13 dent facet or aspect, the invention is a method for reduc-  
14 ing band effects in incremental printing of an image. The  
15 method includes the step of printing a region of the image  
16 at less than full (100%) coverage.

17 It also includes the step of — in order to compen-  
18 sate for error in colorant placement — adding further  
19 colorant quanta to selected pixels already receiving col-  
20 orant as part of the less-than-full coverage within the  
21 region. Thereby, within the region, the amount of colo-  
22 rant printed in some pixels is zero, in others is one col-  
23 orant quantum, and in still others is two or more colorant  
24 quanta.

25 The definitions, permitted ranges and other under-  
26 standings discussed above in relation to the first facet  
27 of the invention are generally applicable here too — and  
28 as well to other invention aspects discussed below.

29  
30 The foregoing may represent a description or defini-  
31 tion of the second aspect or facet of the invention in its  
32 broadest or most general form. Even as couched in these  
33 broad terms, however, it can be seen that this facet of  
34 the invention importantly advances the art.

1           In particular, this aspect of the invention is spe-  
2           cifically directed to reduction of the class of banding  
3           effects that arise through error in colorant placement.  
4           It is first to attack this problem by use of the added-  
5           colorant technique.

6  
7           Although the second major aspect of the invention  
8           thus significantly advances the art, nevertheless to opti-  
9           mize enjoyment of its benefits preferably the invention is  
10          practiced in conjunction with certain additional features  
11          or characteristics. In particular, if the invention is  
12          printing an area fill at less than double (200%) coverage,  
13          in another region of the image, then preferably the method  
14          also includes the step of adding — within that other  
15          region — further colorant to selected pixels already  
16          receiving colorant as part of the area fill.

17          Another preference, is that the method further in-  
18          clude the step of at least approximately maintaining a  
19          particular ratio between the "still other pixels" and the  
20          pixels receiving colorant as part of the less-than-full  
21          coverage within the region.

22  
23  
24          In preferred embodiments of its third major indepen-  
25          dent facet or aspect, the invention is a method of adding  
26          colorant in a region to which colorant is already ad-  
27          dressed, in incremental printing of an image. The method  
28          includes the step of automatically establishing a ratio of  
29          number of added-colorant pixels to total number of ad-  
30          dressed pixels.

31          It also includes the step of setting the ratio to a  
32          value below one-half. Furthermore it includes the step of  
33          automatically printing a region of the image with the ad-  
34          ded-colorant pixels included at that ratio.

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1           The foregoing may represent a description or defini-  
2           tion of the third aspect or facet of the invention in its  
3           broadest or most general form. Even as couched in these  
4           broad terms, however, it can be seen that 'this facet of  
5           the invention importantly advances the art.

6           In particular, this aspect of the invention focuses  
7           upon an advantageous range for parallel growth of single  
8           and plural colorant quanta within a common tonal-gradation  
9           sequence — advantageous because it is low enough to avoid  
10          objectionable clumping or graininess of added dots. Thus  
11          the third facet of the invention in principle can start  
12          from essentially zero inking and proceed through full dot  
13          addressing.

14  
15          Although the third major aspect of the invention thus  
16          significantly advances the art, nevertheless to optimize  
17          enjoyment of its benefits preferably the invention is  
18          practiced in conjunction with certain additional features  
19          or characteristics. In particular, preferably the setting  
20          step includes setting the ratio to a value between 0.15  
21          and 0.4, inclusive — an optimum range, high enough to be  
22          effective but well distanced from the onset of graininess  
23          at or above roughly the 50% point.

24          Another preference is that the setting step include a  
25          human operator selection to trade off banding robustness  
26          against granularity. Other preferences in regard to the  
27          third main facet of the invention relate to express indi-  
28          cations — discussed above for the first aspect of the  
29          invention — of increasing banding robustness vs. decreas-  
30          ing granularity, on a scale for operator reference in man-  
31          ually selecting a setting.

32  
33



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1           In preferred embodiments of its fourth major indepen-  
2       dent facet or aspect, the invention is a method of adding  
3       colorant in a region to which colorant is already ad-  
4       dressed, in incremental printing of an image. The method  
5       includes the step of automatically adding colorant by se-  
6       lectively employing a superpixel that is very insensitive  
7       to characteristics of dot placement error. It also in-  
8       cludes the step of automatically printing a region of the  
9       image with that added colorant.

10

11           The foregoing may represent a description or defini-  
12       tion of the fourth aspect or facet of the invention in its  
13       broadest or most general form. Even as couched in these  
14       broad terms, however, it can be seen that this facet of  
15       the invention importantly advances the art.

16           In particular, this aspect of the invention is a par-  
17       ticularly sophisticated and powerful antiartifact tech-  
18       nique. Making selective use of output data structures  
19       that are consistent in their visual properties, even in  
20       the presence of strongly varying placement error, is unu-  
21       sually effective.

22

23           Although the fourth major aspect of the invention  
24       thus significantly advances the art, nevertheless to  
25       optimize enjoyment of its benefits preferably the inven-  
26       tion is practiced in conjunction with certain additional  
27       features or characteristics. In particular, preferably  
28       the superpixel is intermediate in characteristics between

29

30                           1 0                           2 0  
31                           0 1                           and                           0 0,  
32

33       or in abbreviated notation, explained in the detailed de-  
34       scription that follows, [1 0; 0 1] and [2 0; 0 0]. Anoth-

1 er preference is that the superpixel be selected from the  
2 group consisting of [2 0; 0 2], [1 0; 1 0], [1 1; 0 0],  
3 [0 0; 1 1], [0 1; 0 1].  
4  
5

6 In preferred embodiments of its fifth major indepen-  
7 dent facet or aspect, the invention is a method of incre-  
8 mental printing of an image by construction from individ-  
9 ual colorant quanta addressed to pixels of a printing  
10 grid. The method includes the steps of automatically ad-  
11 dressing a first number of colorant quanta to some pixels;  
12 and automatically addressing a second number of colorant  
13 quanta to other pixels — the second number being larger  
14 than the first.

15 These two steps are both performed for substantially  
16 all tonal levels in a range extending at least from high-  
17 light regions to midtones. Another step is automatically  
18 printing a region of the image with the added colorant.  
19

20 The foregoing may represent a description or defini-  
21 tion of the fifth aspect or facet of the invention in its  
22 broadest or most general form. Even as couched in these  
23 broad terms, however, it can be seen that this facet of  
24 the invention importantly advances the art.

25 In particular, by concurrently maintaining parallel  
26 different magnitudes of colorant over such a high range of  
27 tonal levels, this aspect of the invention conveys an un-  
28 precedented freedom from image-quality artifacts.  
29

30 Although the fifth major aspect of the invention thus  
31 significantly advances the art, nevertheless to optimize  
32 enjoyment of its benefits preferably the invention is  
33 practiced in conjunction with certain additional features  
34 or characteristics. In particular, preferably the range

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1 extends at least from ten percent area fill through forty  
2 percent area fill. Also preferably the "other" pixels are  
3 selected from among the "some" pixels substantially at  
4 random.

5  
6  
7 All of the foregoing operational principles and  
8 advantages of the present invention will be more fully  
9 appreciated upon consideration of the following detailed  
10 description, with reference to the appended drawings, of  
11 which:

12  
13  
14  
15 BRIEF DESCRIPTION OF THE DRAWINGS

16  
17 Fig. 1 is a pair of enlarged conceptual diagrammatic  
18 views of a few pixels in a pixel grid, showing the effects  
19 of dot placement error (DPE) in a prior-art environment;

20 Fig. 2 is a graph showing how the number of pixels  
21 receiving plural dots grows with increasing tone level in  
22 a simple prior-art system, characterized in the present  
23 document as "dumb double dotting" (DDD) — in which all  
24 pixels receiving any dots at all receive a fixed plural  
25 number of dots;

26 Fig. 3 is a like graph showing the growth of numbers  
27 of pixels receiving either one dot or two dots, with in-  
28 creasing tone level, on a two-drop printing medium in the  
29 prior art;

30 Fig. 4 is a like prior-art graph but for a three-drop  
31 printing medium;

32 Fig. 5 is an enlarged pixel view like Fig. 1 but ac-  
33 cording to preferred embodiments of the invention, i. e.  
34 so-called "discretionary dotting" (DD);

1           Fig. 6 is a pixel-growth graph for a two-drop print  
2 medium — like Fig. 3, but according to preferred embodi-  
3 ments of the invention;

4           Fig. 7 is a like graph but for a three-drop medium,  
5 for comparison with Fig. 4 but also according to preferred  
6 embodiments;

7           Fig. 8 is a pair of enlarged views generally similar  
8 to Fig. 1 but showing overlap ratios for two extreme cases  
9 of adjacent dot placement, for discussion of sensitivity  
10 to dot placement error and DD fraction;

11           Fig. 9 is a highly conceptual graph showing the  
12 tradeoff effects of banding vs. grain with increasing DD;

13           Fig. 10 is a conceptual diagram showing basic bit  
14 management for implementing the Fig. 6 or 7 strategy;

15           Fig. 11 is a like diagram following the results of  
16 the Fig. 10 bit management through the remainder of the  
17 implementation;

18           Fig. 12 is a group of diagrams that illustrate, in  
19 the spatial-frequency domain, how preferred embodiments  
20 affect banding — the upper two sketches being respective-  
21 ly plan and isometric views of prior-art banding, and the  
22 lower two being like views of potentially the same banding  
23 but after mitigation by the present invention;

24           Fig. 13 is a perspective view of the exterior of a  
25 printing device embodying preferred embodiments of the  
26 invention;

27           Fig. 14 is a like view of a scanning carriage and me-  
28 dium-advance mechanism in the Fig. 13 device;

29           Fig. 15 is a highly schematic diagram of the working  
30 system of the Fig. 13 and 14 device, particularly as used  
31 to practice preferred embodiments of the third above-in-  
32 troduced aspect of the invention; and

Fig. 16 is a flow chart showing operation of the Fig. 13 and 14 device, particularly as used to practice the first, second and fourth aspects of the invention.

DETAILED DESCRIPTION  
OF THE PREFERRED EMBODIMENTS

1. CONCURRENT PLURAL-DROP DEVELOPMENT

Another way to recognize the principles and practice of the invention, as introduced in the above summary section, is to see that the prior-art graphs of Figs. 2 through 4 are no longer applicable. It is no longer true that two-drop pixel growth 127 (Figs. 3 and 4) cannot begin until single-drop growth 125 has topped out and the system thereby reached an intermediate breakpoint 124.

Instead the number 136 (Fig. 6) of single-drop pixels and the number 137 of double-drop pixels both begin from the very smallest fractions of fill and the very finest saturations, at the origin 121. The total number of addressed pixels is the sum of the one-drop pixels 136 and two-drop pixels 137.

In preferred embodiments the two-drop pixel count 137 is some fraction — preferably a fixed fraction — of the single-drop count 136. The value of this fraction determines the banding/graininess tradeoff mentioned earlier, and may be set either automatically by the system in response to known image characteristics militating one way or the other, or manually by the operator based on human esthetic evaluation — or by a combination of both.

1 Analogously it is no longer true that three-drop  
2 growth 133 (Fig. 4) cannot begin until after two-drop pix-  
3 el growth has topped out and the system thereby reached a  
4 second breakpoint 131. Instead the number of triple-drop  
5 pixels 142 (Fig. 7) grows, from the outset, in a relation-  
6 ship (preferably a fixed proportion) to the number of  
7 single-drop and double-drop pixels 136, 137.

8 In a word, according to the invention the development  
9 of plural-drop pixels 137, 142 is concurrent with that of  
10 single-drop pixels 136. The invention posits the coexis-  
11 tence of some pixels with one drop, others with two, and  
12 potentially others with three or more drops.

13 Again, the objective is greater robustness to banding  
14 than attainable through conventional orderly multilevel  
15 printing. The invention may be described as "discretion-  
16 ary dotting" (DD) — by contrast with the inflexible pri-  
17 or-art rule of "dumb double dotting" described earlier.

18 Within the category of DD, a relatively simple case  
19 is "double dotting" (as distinguished from "dumb double  
20 dotting"). In double dotting, some number of dots that  
21 make up the conventional dots is boosted up to double that  
22 number.

23 It is just one form of discretionary dotting, since  
24 multipliers other than two are entirely possible and  
25 within the scope of the invention. For example, if the  
26 conventional dots occur always in pairs (dumb double  
27 dotting) — two dots within a respective single pixel —  
28 the present invention can be used to add one discretionary  
29 dot to the statistically selected pixels.

30 Conversely if conventional dots occur always individ-  
31 ually in respective single pixels, the present invention  
32 in principle can be used to add pairs or even triplets,  
33 etc. (Granularity due to such technique may be disadvan-

1 taneous in many cases, but the method remains within the  
2 scope of the appended claims.)

3  
4  
5 2. THE "DD RATIO" AND ITS IMPLICATIONS

6  
7 Thus the previously mentioned fraction of backup col-  
8 orant quanta per pixel, the DD ratio, may be employed in  
9 describing double dotting — but with great care, as the  
10 term "DD ratio" may also be used for cases in which the DD  
11 multiplier is not two. As will be clear, a like ratio may  
12 be defined if desired for triple dotting.

13 As an example, a DD ratio of 0.33 — in other words  
14 33% DD — simply means that one out of every three pixels  
15 which will be printed at all will receive some number of  
16 drops greater than the conventional number. For instance  
17 that might be a total of two drops, or one and a half  
18 drops on-average, rather than one. Eventually if the pix-  
19 els in the grid are all addressed by such a scheme, then  
20 continuing the same two examples the number of colorant  
21 quanta on the printing medium will be:

22  
23  $100\% + 1 \times 33\% = 133\%, \text{ or}$

24  
25  $100\% + 1\frac{1}{2} \times 33\% = 150\%,$

26  
27 relative to the number of colorant quanta in a conventio-  
28 nal printing system.

29 If desired, however, when the multiplier is one the  
30 application of colorant may continue beyond the 133%-dot-  
31 ted point, to a double-density or 200% area fill (i. e.,  
32 by definition in this document an area fill that is 200%  
33 dotted) or higher — continuing, for example, on to a  
34 triple-density, 300%, fill (i. e. a fill that is by defi-

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1 nition 300% dotted). The discussion and diagrams already  
2 presented should make clear, to a person of ordinary skill  
3 in this field, what to do to implement these goals, pro-  
4 vided only that the printing system is capable of render-  
5 ing and delivering the greater number of dots desired.

6  
7 Certain DD ratios can be recognized as not discretio-  
8 nary dotting at all, but rather as prior-art systems.  
9 Thus 0% DD corresponds to the conventional orderly multi-  
10 level printing, and 100% DD corresponds to dumb double  
11 dotting — since every printed pixel has two drops, for  
12 any area fill percentage).

13 In practice, banding decreases as the DD ratio moves  
14 up to 0.5. In most cases, it disappears altogether before  
15 reaching that point.

16 The range from DD 0.5 to 1.0 has not been characte-  
17 rized as it does not, to-date, appear practically useful.  
18 As noted above, granularity increases with the DD ratio;  
19 hence minimum grain is achieved with the orderly multilev-  
20 el printing. It is desirable to select a DD ratio low  
21 enough to avoid exaggerated granularity, but high enough  
22 to reduce or even remove banding.

23 The relationship between banding improvement and  
24 graininess (Fig. 9) has an optimum DD ratio value, gener-  
25 ally between DD 0 and 0.5 — but the exact value that is  
26 optimum and the actual shape of the curve vary with image  
27 characteristics as well as system characteristics. Hence  
28 the selection of an operating point within the usually op-  
29 timum range may be best reserved for run time.

30 Pixels with various numbers of drops are advanta-  
31 geously distributed in the pixel grid under control of a  
32 matrix that controls which pixels in an area fill receive  
33 double or triple etc. dotting. The function that manages



1 this distribution of varied numbers of drops may be termed  
2 a "bidimensional noise function".

3 This noise-function matrix will interact with the  
4 noise of halftoning algorithms — for instance an error-  
5 diffusion process. Therefore the bidimensional noise  
6 function is advisably coordinated with — or ideally inte-  
7 grated into — rendering and printmasking.

8 In other words, in principle both pixel-content con-  
9 trol and noise spatial-frequency-content control can be  
10 accomplished by using the rendition or printmasking sys-  
11 tems that are native to the printer, if those systems are  
12 adequately sophisticated. In this regard the earlier-men-  
13 tioned patent document of Lain et al. teaches a superpixel  
14 system that performs these tasks.

### 15 16 17 3. SUPERPIXEL FAMILIES, AND OPTIMIZING ROBUSTNESS

18  
19 A preferred embodiment of the present invention op-  
20 erates in a specialized environment that is detailed in  
21 the above-mentioned Lain document. In that environment,  
22 rendition (preferably ED) is performed on a 12 dot/mm (300  
23 dpi) pixel grid.

24 Then the results are applied to select one superpixel  
25 from a family of two-by-two, 24 dot/mm superpixels. The  
26 rendered image is then printed using a printing device  
27 that operates at 24 dot/mm resolution.

28 Each pixel at the 12 dot/mm resolution therefore is  
29 implemented as a two-by-two, 24 dot/mm superpixel. A nat-  
30 ural way to implement the present invention therefore is  
31 to form two-by-two superpixels that most effectively in-  
32 voke DD for antibanding robustness.

33 Generally speaking, the objective for discretionary  
34 dotting is to place within such a superpixel two dots

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1 instead of one — or three instead of two, or some given  
2 larger number instead of some given smaller number. The  
3 absolute number of dots, however, can be ignored for  
4 present purposes, and the question reduced simply to how  
5 best to add a dot.

6 A first observation here is that there are two ex-  
7 tremes cases that nicely define the range of possibilities.  
8 For discussion arbitrarily suppose that a dot 151 (Fig. 8,  
9 both views) is placed in a superpixel 150 in its top left  
10 quadrant — pixel TL — i. e. in position (1,0); and then  
11 that its backup is either:

12  
13 (1) discretionary dot 152 in the diagonally opposite  
14 quadrant of the superpixel, i. e. bottom right pixel  
15 BR at position (0,1), as in the upper view; or

16  
17 (2) discretionary dot 153 directly superimposed on the  
18 first-mentioned dot, i. e. at position (1,0), as in  
19 the lower view.

20  
21 The first of these choices distributes the inking on  
22 the printing medium as evenly as possible. Only the small  
23 football-shaped areas are inherently double inked; even  
24 the remaining small fractions of the top-right and bottom-  
25 left pixels TR, BL are wholly inked by other superpixels.

26 From simple geometrical relationships in the drawing,  
27 these double-inked areas in the aggregate amount to less  
28 than three-fifths of the total inked area, i. e. of the  
29 entire four-small-pixel superpixel. (This fraction is a  
30 very different parameter from the DD ratio mentioned ear-  
31 lier — and also further discussed below.)

32 This superpixel is [1 0; 0 1], which is an in-text  
33 representation of —  
34

1                   1 0  
2                   0 1

3

4 — in other words having dots in upper left and bottom  
5 right. The in-text notation presents first the top line  
6 of the two-by-two array, and then the bottom line.

7       This first, diagonal-geometry choice minimizes blank  
8 space. It also minimizes the mutual overlap of the two  
9 dots.

10       The second, superposition-geometry choice does the  
11 opposite — clumping the inking as much as possible by  
12 placing one dot on top of the other, maximizing blank  
13 space and also maximizing the overlap: all of the inked  
14 area is double inked. This superpixel 150' is [2 0; 0 0],  
15 in other words having two dots in top-left quadrant TL,  
16 leaving each of the other three quadrants TR, BL, BR to be  
17 only partially inked from adjacent superpixels.

18       The L\* value is distinctly different for these two  
19 cases, being higher for the superposition geometry because  
20 it presents some white area that makes it more luminous.  
21 Of far greater interest is what happens when these ideal-  
22 ized patterns are disrupted by DPE, for the objective of  
23 this analysis is to find the most useful way to place a  
24 discretionary dot — for robustness in the face of DPE.

25       As the diagonal geometry already has the smallest  
26 possible L\* for a two-drop superpixel, its mean luminance  
27 can only increase with onset of DPE. Conversely, since  
28 the superposition geometry already has the largest possi-  
29 ble L\* for a two-drop superpixel, its mean luminance can  
30 only decrease with DPE.

31       A third member 150" (Fig. 8A) in the two-drop super-  
32 pixel family can also be considered: [1 0; 1 0], or in  
33 other words with dots 154, 154' vertically adjacent, at  
34 upper left and lower left in the superpixel. Of course

1 the relative space-filling properties of this vertical  
2 geometry are the same as for its three rotational cousins  
3 [1 1; 0 0], with both dots horizontally adjacent in the  
4 top of the superpixel; [0 1; 0 1], with both dots verti-  
5 cally adjacent at the right side; and [0 0; 1 1], with  
6 both dots horizontally adjacent at the bottom.

7 This adjacency geometry, with its dot centers closer  
8 together, presents more overlap than the diagonal case but  
9 of course less than the superposition case. Hence either  
10 increase or decrease of  $L^*$  is possible with rising DPE,  
11 depending on the character of the misplacement.

12 Because  $L^*$  will rise in some instances and fall in  
13 others, the mean  $L^*$  for the adjacency geometry is less  
14 sensitive to variations in DPE than either of the other  
15 two geometries. This intermediate geometry is thus most  
16 robust to DPE variation, and accordingly is preferred.

17 Although the embodiments which are now preferred use  
18 two-dot superpixels, the invention — and the broad pref-  
19 erence just described — are more general than the forego-  
20 ing discussion of two-dot superpixel families. A like  
21 preference for intermediate  $L^*$  behaviors will be observed  
22 generally for any  $n$ -dot family: typically a couple of su-  
23 perpixels will have the minimum and maximum  $L^*$ , and all  
24 others will be somewhere between.

25 Without belaboring what will now be evident, those  
26 intermediate geometries are the least sensitive to variant  
27 DPE characteristics and therefore are the most robust in  
28 response to DPE. Actual values of sensitivity to DPE have  
29 been calculated by simulation and to a lesser extent meas-  
30 ured by empirical observation, but again the conclusions  
31 from these efforts are of greater value and are readily  
32 summarized:

33 Discretionary-dotted pixels show a trend toward de-  
34 creasing luminosity, whereas single-dotted pixels tend to

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1 increase it — and to do so in a more sensitive way. Thus  
2 having a few discretionary-dotted pixels balances the up-  
3 ward trend of single-dotted pixels.

4 The least-sensitive two-by-two superpixel interest-  
5 ingly appears to be [2 0; 0 2], with two dots placed in  
6 each of two diagonally opposed corners. This geometry  
7 150"" (Fig. 8B) combines the two earlier-described extreme  
8 geometries (diagonal and superposed), which accordingly  
9 strongly complement one another.

#### 10 11 12 4. PIXEL MANAGEMENT AND SPATIAL FREQUENCY

13  
14 To implement a design DD ratio, finished binary tonal  
15 levels 155-158 (Fig. 10) from a rendering process (such as  
16 ED) are made to serve as pointers to nominally related  
17 pixel groups 165-168, respectively — which will here be  
18 called pixel "families". The illustration corresponds to  
19 an actually implemented exemplary system that both renders  
20 and prints at 24 dot/mm. The families have "members" that  
21 are numbered down the left-hand edge of the diagram.

22 Some of the tonal levels 155, 158 may be (this is not  
23 a requirement) most naturally interpreted as identities in  
24 the respective families, e. g. for zero inking and full  
25 inking respectively, as shown. Members of other families  
26 advantageously diverge from the nominal values.

27 Such divergence is suggested for the binary levels  
28 "01" and "10" (i. e. decimal "1" and "2" respectively).  
29 In particular the input level 156, which has value "01",  
30 is a pointer 176 to a family 166 of pixels seen as in-  
31 cluding an equal number of "01" and "11" pixels and there-  
32 by assuming average tonal value of decimal  $1\frac{1}{2}$ .

33 In this way the first step may be taken toward rais-  
34 ing the printed output level relative to the input tonal

level; however, as will shortly be seen the opportunities for control are more extensive and subtle than indicated so far. This first step appears also in the pointer usage of input level 157, which has tone value "10" but points to a family with equal numbers of members at "10" and "11", thus assuming average tonal value of decimal  $2\frac{1}{2}$ .

A more complete picture of the mapping process, for an embodiment that both renders and prints at 24 dot/mm, requires consideration of four numerical arrays:

- the input image or "plot" data 161 (Fig. 11),
- a randomization matrix 162, usually prepared as part of system design,
- a pixel selection table 163, and
- the selected output grid 164 with its selected pixels.

In each of these tables two values that will be of particular interest appear in boldface type.

The pixel selection table 163 is identical to the level/family mapping of Fig. 10, but only in a more-compact showing: the tonal levels 155-158 appear in the left-hand column headed "plot value", and the families are in corresponding rows, arrayed in the remaining four columns to the right.

The family-member numbers "#1" through "#4" appear as headings for those columns. Some differences, however, will be seen in the specific numbers in the table 163 vs. the previous drawing (Fig. 10).

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1           Entry into the pixel selection table 163 is from two  
2 directions at once: rows are selected by the input-data  
3 tones, read 179 directly from the input data values; while  
4 columns are selected by values from the randomization ma-  
5 trix 162. Values from that matrix 162 in turn are mapped  
6 from the input-data grid locations.

7  
8           The family 166A . . . 166D appearing with tonal level  
9 156 (value "01") here has three entries of "01", and just  
10 one entry 166D of "10" (in boldface), in the far right-  
11 hand column — column "#4". Hence the average output to-  
12 nal value might be supposed to be  $1\frac{1}{4}$ .

13           The actual output tone, however, is not determined  
14 thus but rather by controlling the relative number of oc-  
15 currences of the entries in the several columns. In other  
16 words, control is exerted by defining the number of times  
17 that each pixel will be selected, in operation of the  
18 system.

19           That control of relative incidence is expressly the  
20 function of the randomization matrix 162. Thus for exam-  
21 ple the entry 166D in column #4 will be selected whenever  
22 the numeral "4" (seen in boldface) is cued 174 into the  
23 pixel selection table from — for instance — the position  
24 173 in the first column, second row of that matrix.

25           Tracing the control further upstream 172: as stated  
26 above, the operative position 173 in the randomization ma-  
27 trix 162 is called by the grid location 171 in the image  
28 data 161. The entry there, "01" (also shown in boldface),  
29 as will be recalled serves 179 as the row selector into  
30 the pixel selection table 163.

31  
32           For the example under consideration, it remains to  
33 follow the pixel selection table causal links downstream.  
34 Once the pixel "10" at 166D is thus identified, that

1 particular unit is transferred 175 to the output grid 164  
2 — which now has a corresponding entry 166D' in the same  
3 relative position as the originating pixel 171 in the  
4 input data.

5 The image-data location, in other words, is used  
6 twice: once mapping into the randomization matrix 162,  
7 and then again receiving the designated pixel 166D into  
8 the output pixel grid 164. The example traced so far is  
9 perhaps of particular interest in that:

- 11     ▪ the value "10" at 166D in the selection table 163  
12         appears only once in its family, and
- 13
- 14     ▪ the value "4" that calls it — at 173 in the random-  
15         ization matrix 162 — appears only once in that  
16         entire matrix.

17

18 Hence the example chosen to begin this tutorial ex-  
19 ercise represents a very fine adjustment in the overall  
20 behavior of the pixel selection system, as an implementa-  
21 tion of the present invention. The binary input tone  
22 "01", for the particular numbers used, is raised to a bi-  
23 nary output tone "10" — i. e. from decimal "1" to "2".

24 A much less unusual sequence of entries can be fol-  
25 lowed, but this time starting with the beginning of the  
26 process —

- 27
- 28     ▪ from the boldface input-data point 181, of value  
29         "10",
- 30
- 31     ▪ across 182 to a boldface entry 183 (value "1") in the  
32         randomization matrix 162, and thence



1       ▪ down 184 to a boldface entry 167A (value "11") in the  
2       pixel selection table 163, and finally

3  
4       ▪ down to a boldface entry 167A' (value "11") in the  
5       output grid 164.

6  
7       Here the input-data point 181 (value "10") also  
8       points to the family "10" (third row in the body of the  
9       pixel selection table). To avoid further clutter of the  
10      drawing, this particular causal path is not marked.

11      In the randomization matrix 162, there are five en-  
12      tries (out of twelve total) with value "1" — i. e. the  
13      same as the example just traced. In the pixel selection  
14      table 163, for family "10" there are two entries (out of  
15      five total).

16      Therefore this example represents an instance of rel-  
17      atively broad-brush control such as establishes a main nu-  
18      merical trend of the system. Specifically the result for  
19      the exemplary numbers used is that the binary input tone  
20      "10" is raised to an output tone "11", i. e. from decimal  
21      "2" to "3".

22      Yet another kind of control begins in the image-data  
23      grid 161 with a pixel position 191 (tone level "01"), pro-  
24      ceeding across 192 to an entry 193 of value "1" in the  
25      randomization matrix. Again to avoid adding to the com-  
26      plexity of the drawing, the remaining links have not been  
27      marked — but it will be understood that the randomization  
28      value "1" will call column #1 in the pixel table 163,  
29      while the tonal value "01" calls family row "01" in that  
30      table 163.

31      The pixel at the intersection of this column and row  
32      is 166A, with value "01" — and this value is transferred  
33      to the output grid at position 166A'. The output value  
34      for position 166A' remains "01", the same as the input

value for the same pixel position 191. This case thus produces no value change at all.

In short, the fraction of discretionary dotting is determined by the randomization matrix, and any ratio between zero and unity can be achieved — not only zero or unity as in the prior art. One representative specific implementation was developed as follows.

- A Shakes printmask was designed for a twelve-pass printmode. This mask was 256x256, and contained values from "1" to "12", each appearing  $1/12 = 8.33\%$  of the time.
- Original values "1" through "4" were left undisturbed, but all occurrences of "5" were replaced by "2", and all instances of "6" and "7" by 3. The rest of the numbers (i. e. "8" through "12") were replaced by "4".
- In the resulting randomization matrix, "1" appears 8.33% of the time, "2" appears 16.67% of the time, "3" appears 25% of the time, and "4" the remaining 50% of the time.
- Out of the four members of the family, any member may be chosen to have a discretionary dot. If member "1" is so chosen, then (since "1" appears only once in twelve entries on-average) the system should produce 8.33% discretionary dotting — i. e. a DD ratio of  $1/12$  or 8.33%. If member #4 has the double dot, then discretionary dotting should occur half the time, DD  $1/2$ .

1       ■ The specific implementation under discussion assigned  
2       discretionary dotting to members "2" and "3" of the  
3       pixel family, corresponding to discretionary dotting  
4       of  $16.67\% + 25\% = 41.67\%$ .

5  
6       Thus a readily achieved ratio when averaging a 256x256-  
7       pixel area is roughly DD 42%, near the optimum range. In  
8       round numbers, roughly two out of every five dots are  
9       doubled.

10  
11       Not all banding is equal, and banding need not be  
12       removed completely to produce major improvement in image  
13       appearance. These truths may be particularly clear from  
14       considering banding in the frequency domain.

15       Suppose "horizontal" (Fig. 12, view A) is defined as  
16       an axis of spatial frequencies localized in an incre-  
17       mental-printing scan direction (usually the transverse,  
18       right-to-left direction of a piece of printing medium);  
19       and "vertical" is defined as an axis of spatial frequen-  
20       cies localized in the printing-medium advance direction  
21       (usually the longitudinal direction). A third axis, "pow-  
22       er" is orthogonal to both the horizontal and vertical  
23       axes.

24       Two arrows 194 appear going into the plane of the  
25       paper in view A — which is looking upward into the  
26       vertical-horizontal plane. Two arrows 195 appear upstand-  
27       ing in the power-vertical plane in view B (isometric).

28       Actually the arrows 194 and 195 both represent the  
29       identical quantity, namely power in banding as a function  
30       of spatial frequency — for conventional light/white-line  
31       banding. As usual these graphs are symmetrical.

32       The illustrated frequency localization of banding is  
33       very sharp. It is a clean, not grainy banding and appears  
34       very distinctively.

1           This may be the kind of banding that is seen when  
2 everything in an image is sharply-tuned, and the banding  
3 appears very distinctively. Unfortunately this is the  
4 most natural character for banding as ordinarily generated  
5 by weak or misaimed printing elements (e. g. nozzles).

6           Such high-Q banding, like a high-Q signal of any  
7 type, is generally most sensitively detected and per-  
8 ceived. For present purposes this is undesirable.

9  
10           The two lower figures represent the same banding, but  
11 at low Q. The energy 196 seen in the vertical-horizontal  
12 plane of view C — again, the same energy 197 seen in the  
13 isometric view D that more clearly exhibits the power axis  
14 — has been somewhat spread away from the central fre-  
15 quency point, and each sharp impulse function has become  
16 blunted and diffused.

17           This is precisely the result that may be expected  
18 from applying the techniques of the present invention.  
19 That is to say, the banding is not truly eradicated but  
20 rather is obscured and confused, muddled in the field of  
21 randomly scattered discretionary dots 115 (Fig. 5). In  
22 short, the banding is still there but more blurred so that  
23 it is much less conspicuous — and in some cases perhaps  
24 invisible to the eye.

## 25 26 27   5. MECHANICAL AND PROGRAM/METHOD FEATURES

28  
29           The invention is amenable to implementation in a  
30 great variety of products. It can be embodied in a prin-  
31 ter/plotter that includes a main case 1 (Fig. 13) with a  
32 window 2, and a left-hand pod 3 which encloses one end of  
33 the chassis. Within that enclosure are carriage-support  
34 and -drive mechanics and one end of the printing-medium

1 advance mechanism, as well as a pen-refill station with  
2 supplemental ink cartridges.

3 The printer/plotter also includes a printing-medium  
4 roll cover 4, and a receiving bin 5 for lengths or sheets  
5 of printing medium on which images have been formed, and  
6 which have been ejected from the machine. A bottom brace  
7 and storage shelf 6 spans the legs which support the two  
8 ends of the case 1.

9 Just above the print-medium cover 4 is an entry slot  
10 7 for receipt of continuous lengths of printing medium 4.  
11 Also included are a lever 8 for control of the gripping of  
12 the print medium by the machine.

13 A front-panel display 211 and controls 212 are moun-  
14 ted in the skin of the right-hand pod 213. That pod en-  
15 closes the right end of the carriage mechanics and of the  
16 medium advance mechanism, and also a printhead cleaning  
17 station. Near the bottom of the right-hand pod for readi-  
18 est access is a standby switch 214.

19 Within the case 1 and pods 3, 213 a cylindrical plat-  
20 en 241 (Fig. 15) — driven by a motor 242, worm and worm  
21 gear (not shown) under control of signals from a digital  
22 electronic processor 71 — rotates to drive sheets or  
23 lengths of printing medium 4A in a medium-advance direc-  
24 tion. Print medium 4A is thereby drawn out of the print-  
25 medium roll cover 4.

26 Meanwhile a pen-holding carriage assembly 220 (Figs.  
27 14 and 15) carries several pens 223-226 (Fig. 14) back and  
28 forth across the printing medium, along a scanning track  
29 — perpendicular to the medium-advance direction — while  
30 the pens eject ink. For simplicity's sake, only four pens  
31 are illustrated; however, as is well known a printer may  
32 have six pens or more, to hold different colors — or dif-  
33 ferent dilutions of the same colors as in the more-typical  
34 four pens. The medium 4A thus receives inkdrops for for-

1 mation of a desired image, and is ejected into the print-  
2 medium bin 5.

3  
4 A very finely graduated encoder strip 233, 236 (Fig.  
5 15) is extended taut along the scanning path of the car-  
6 riage assembly 220 and read by another, very small auto-  
7 matic optoelectronic sensor 237 to provide position and  
8 speed information 237B for the microprocessor. One advan-  
9 tageous location for the encoder strip is shown in several  
10 of the earlier cross-referenced patent documents at 236,  
11 immediately behind the pens.

12 A currently preferred position for the encoder strip  
13 33 (Fig. 14), however, is near the rear of the pen-car-  
14 riage tray — remote from the space into which a user's  
15 hands are inserted for servicing of the pen refill car-  
16 tridges. For either position, the sensor 237 is disposed  
17 with its optical beam passing through orifices or trans-  
18 parent portions of a scale formed in the strip.

19 The pen-carriage assembly 220, 220' (Fig. 15) is  
20 driven in reciprocation by a motor 231 — along dual  
21 support and guide rails 232, 234 — through the intermedi-  
22 ary of a drive belt 235. The motor 231 is under the con-  
23 trol of signals from digital processors 71.

24 Naturally the pen-carriage assembly includes a for-  
25 ward bay structure 222 for pens — preferably at least  
26 four pens 223-226 holding ink of four different colors  
27 respectively. Most typically the inks are yellow in the  
28 leftmost pen 223, then cyan 224, magenta 225 and black  
29 226. As a practical matter, chromatic-color and black  
30 pens may be in a single printer, either in a common car-  
31 riage or plural carriages.

32 Also included in the pen-carriage assembly 220, 220'  
33 is a rear tray 221 carrying various electronics. Figs. 13  
34 and 14 most specifically represent a system such as the

1 Hewlett Packard printer/plotter model "DesignJet 2000CP",  
2 which does not include the present invention. These  
3 drawings, however, also illustrate certain embodiments of  
4 the invention, and — with certain detailed differences  
5 mentioned below — a printer/plotter that includes pre-  
6 ferred embodiments of the invention.

7  
8 Before further discussion of details in the block  
9 diagrammatic showing of Fig. 15, a general orientation to  
10 that drawing may be helpful. This diagram particularly  
11 represents preferred embodiments of the previously dis-  
12 cussed apparatus aspect of the invention.

13 Conventional portions of the apparatus appear as ele-  
14 ments 70, 72, 76', 78 and 101 at the left end of Fig. 15,  
15 and also the printing stage 220, 220', 241, 242, 237.  
16 Also generally conventional are related signals 66, 237B,  
17 220B, 220'B, 231A, 242A, and the associated output/print-  
18 mask stage 88 at the far right end of the diagram.

19 Features particularly related to the apparatus aspect  
20 of the invention appear in the central region as elements  
21 96 through 99, 87', and 102 through 107. Given the state-  
22 ments of function and the diagrams presented in this  
23 document, an experienced programmer of ordinary skill in  
24 this field can prepare suitable programs for operating all  
25 the circuits.

26  
27 The pen-carriage assembly is represented separately  
28 at 220 when traveling to the left 216 while discharging  
29 ink 218, and at 220' when traveling to the right 217 while  
30 discharging ink 219. It will be understood that both 220  
31 and 220' represent the same pen carriage.

32 The previously mentioned digital processor 71 pro-  
33 vides control signals 220B, 220'B to fire the pens with  
34 correct timing, coordinated with platen drive control

1 signals 242A to the platen motor 242, and carriage drive  
2 control signals 231A to the carriage drive motor 231. The  
3 processor 71 develops these carriage drive signals 231A  
4 based partly upon information about the carriage speed and  
5 position derived from the encoder signals 237B provided by  
6 the encoder 237.

7 (In the block diagram all illustrated signals are  
8 flowing from left to right except the information 237B fed  
9 back from the sensor — as indicated by the associated  
10 leftward arrow.) The codestrip 233, 236 thus enables for-  
11 mation of color inkdrops at ultrahigh precision during  
12 scanning of the carriage assembly 220 in each direction —  
13 i. e., either left to right (forward 220') or right to  
14 left (back 220).

15 New image data 70 are received 191 into an image-pro-  
16 cessing stage 73, which may conventionally include a con-  
17 trast and color adjustment or correction module 72, and a  
18 rendition module 101. This module includes a block 76',  
19 preferably operating by error diffusion, to determine a  
20 tone value 77 (corresponding to the levels 155-158 in Fig.  
21 10) to be printed at each pixel — and a further block 95  
22 which in effect interprets the tone value 77 as a coverage  
23 fraction.

24 Although generally conventional in its internal  
25 operation, the rendition module 101 preferably operates at  
26 relatively low resolution e. g. 12 dots/mm, for the rea-  
27 sons and in the manner described in the above-mentioned  
28 Lain document. Complementary to this low-resolution ren-  
29 dering, that document also teaches use of a pixel system  
30 for implementing the low-resolution coverage fraction 193'  
31 as a choice of a higher-resolution pixel for printing.

32 (In this document the earlier discussion of Figs. 10 and  
33 11 covers portions of the same ground.)



1 For present purposes, in Fig. 15 that entire pixel  
2 system appears simplified as a small block 87'. Inter-  
3 posed between the rendition module 101 and pixel system  
4 87' are ratio-establishing means 96, which operate to  
5 establish the DD ratio discussed at some length above.

6 These ratio means 96 are preferably controlled by  
7 some means 102 for setting the DD ratio within the optimum  
8 range (Fig. 9), which representatively and preferably is  
9 0.15 to 0.4. Although these means 102 are advantageously  
10 automatic, a manual override or fine-tuning block 103 is  
11 beneficially provided.

12 This manual-input unit 103 if present preferably in-  
13 cludes a slider or a stepper switch 104. The stepper or  
14 slider may be implemented as an on-screen selector in a  
15 graphical user interface of a personal computer, or of  
16 course if preferred as an actual electromechanical slider  
17 or switch.

18 In either event the stepper or slider 104 preferably  
19 operates along a scale 105 accompanied by indicia 106, 107  
20 to expressly present to the user the implication of trad-  
21 ing-off granularity against banding. It will be under-  
22 stood that the system is entirely capable of operation  
23 with no manual-input provision 103-107 at all, if design  
24 philosophy undertakes to establish in the setting means  
25 102 an ideal or acceptable ratio automatically.

26  
27 Output from the ratio-establishing means 96, as con-  
28 ditioned by the setting means 102, is in effect a hierar-  
29 chy 97-99 of pixels receiving different numbers of dots,  
30 e. g. inkdrops. Thus as shown some pixels will receive no  
31 drop 97, others one drop 98 and still others two or more  
32 drops 99.

33 Unlike prior-art systems, the invention enables coex-  
34 istence of these three states on a printing medium simul-

1 taneously. As the drawing suggests, the entire operation  
2 of the image-processing system 73 is advantageously con-  
3 ducted with respect to the four or more colorants of a  
4 subtractive printing system.

5 Thus for instance the output hierarchy may include  
6 cyan C, magenta M, yellow Y and black K plural drops 99,  
7 together with CMYK single drops 98 and CMYK zero drop 97.  
8 Of course the specification of colorant for zero drop is  
9 somewhat a semantic point.

10 The invention is by no means limited to operation in  
11 four-colorant systems. To the contrary, for example six-  
12 colorant "CMYKcm" systems including dilute cyan "c" and  
13 magenta "m" colorant are included in preferred embodi-  
14 ments. The hierarchy of states for each input tonal level  
15 77 is then interpreted by the pixel system 87' to provide  
16 higher-resolution printing.

17  
18 Integrated circuits 71 may be distributive — being  
19 partly in the printer, partly in an associated computer,  
20 and partly in a separately packaged raster image proces-  
21 sor. Alternatively the circuits may be primarily or whol-  
22 ly in just one or two of such devices.

23 These circuits also may comprise a general-purpose  
24 processor (e. g. the central processor of a general-pur-  
25 pose computer) operating software such as may be held for  
26 instance in a computer hard drive, or operating firmware  
27 (e. g. held in a ROM 70 and for distribution 66 to other  
28 components), or both; and may comprise application-spe-  
29 cific integrated circuitry. Combinations of these may be  
30 used instead.

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32  
33 In operation the system retrieves 301 (Fig. 16) its  
34 operating program appropriately — i. e., by reading in-

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1 instructions from memory in case of a firmware or software  
2 implementation, or by simply operating dedicated hardware  
3 in case of an ASIC or like implementation. Once prepared  
4 in this way, the method proceeds to the procedure 301  
5 through 314 as illustrated.

6 Analogously to the preferred hardware embodiment dis-  
7 cussed above, the procedure begins with establishment 302  
8 of the desired DD ratio, establishment 306 of a user in-  
9 terface (which may be either a computer GUI or actual me-  
10 chanical controls). Next are real-time steps including  
11 generation or receipt 308 of image data, preparation 311  
12 for printing including addition of further colorant 312;  
13 and finally printout 314 onto a printing medium.

14 In view of the foregoing it is believed that the per-  
15 son skilled in this field will find the remaining details  
16 of Fig. 16 self explanatory.

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18  
19  
20 The above disclosure is intended as merely exemplary,  
21 and not to limit the scope of the invention — which is to  
22 be determined by reference to the appended claims.